

U.S. FISH AND WILDLIFE SERVICE SPECIES ASSESSMENT AND LISTING PRIORITY ASSIGNMENT FORM

Scientific Name:

Quadrula aurea

Common Name:

golden orb

Lead region:

Region 2 (Southwest Region)

Information current as of:

03/17/2015

Status/Action

☐ Funding provided for a proposed rule. Assessment not updated.

☐ Species Assessment - determined species did not meet the definition of the endangered or threatened under the Act and, therefore, was not elevated to the Candidate status.

☐ New Candidate

☒ Continuing Candidate

☐ Candidate Removal

☐ Taxon is more abundant or widespread than previously believed or not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status

☐ Taxon not subject to the degree of threats sufficient to warrant issuance of a proposed listing or continuance of candidate status due, in part or totally, to conservation efforts that remove or reduce the threats to the species

☐ Range is no longer a U.S. territory

☐ Insufficient information exists on biological vulnerability and threats to support listing

- ☐ Taxon mistakenly included in past notice of review
- ☐ Taxon does not meet the definition of "species"
- ☐ Taxon believed to be extinct
- ☐ Conservation efforts have removed or reduced threats
- ☐ More abundant than believed, diminished threats, or threats eliminated.

Petition Information

☐ Non-Petitioned

☒ Petitioned - Date petition received: 06/25/2007

90-Day Positive: 12/15/2009

12 Month Positive: 10/06/2011

Did the Petition request a reclassification? **No**

For Petitioned Candidate species:

Is the listing warranted (if yes, see summary threats below) **Yes**

To Date, has publication of the proposal to list been precluded by other higher priority listing? **Yes**

Explanation of why precluded:

Higher priority listing actions, including court-approved settlements, court-ordered and statutory deadlines for petition findings and listing determinations, emergency listing determinations, and responses to litigation, continue to preclude the proposed and final listing rules for this species. We continue to monitor populations and will change its status or implement an emergency listing if necessary. The Progress on Revising the Lists section of the current CNOR (<http://endangered.fws.gov/>) provides information on listing actions taken during the last 12 months.

Historical States/Territories/Countries of Occurrence:

- **States/US Territories:** Texas
- **US Counties:** Atascosa, TX, Bandera, TX, Bexar, TX, Blanco, TX, Caldwell, TX, Comal, TX, DeWitt, TX, Gillespie, TX, Goliad, TX, Gonzales, TX, Guadalupe, TX, Hays, TX, Karnes, TX, Kendall, TX, Kerr, TX, Live Oak, TX, Llano, TX, McMullen, TX, Medina, TX, Refugio, TX, San Patricio, TX, Travis, TX, Victoria, TX, Wilson, TX

- **Countries:**Country information not available

Current States/Counties/Territories/Countries of Occurrence:

- **States/US Territories:** Texas
- **US Counties:** Atascosa, TX, DeWitt, TX, Goliad, TX, Gonzales, TX, Karnes, TX, Kerr, TX, Live Oak, TX, McMullen, TX, Refugio, TX, San Patricio, TX, Victoria, TX
- **Countries:**Country information not available

Land Ownership:

Three of known golden orb populations occur in State designated no-harvest sanctuaries including: sections of Guadalupe River in Kerr and Gonzales Counties and San Marcos River in Gonzales County (Howells 2010a, pp. 9-10). Two populations occur within State parks. One population is located within Palmetto State Park in Gonzales County in San Marcos River (Howells 1996, p. 28). The other large population occurs within Goliad State Park, which is located within the lower portion of the San Antonio River in Goliad County (Howells 2009, p. 11). The remaining populations occur in the Nueces-Frio and Guadalupe-San Antonio River systems are adjacent to private land.

Lead Region Contact:

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Biological Information

Species Description:

The golden orb is small, usually less than 82 mm (3.2 in), with an oval to nearly round, smooth, and unsculptured shell, except for concentric growth rings (Howells 2002b, p. 6). External shell coloration varies from yellow-brown, gold, or orangish-brown to dark brown or black, and some individuals may show faint greenish rays. Internally, the nacre (inside of the shell) is white to bluish-white (Howells 2002b, p. 6).

Taxonomy:

The golden orb was originally described as *Unio aureas* by Lea in 1859 and later moved to the genus *Quadrula* in 1900 (Simpson 1900, p. 783). Graf and Cummings (2007, p. 18) have proposed moving it to the genus *Amphinaias*, but other freshwater mussel taxonomists recommend waiting for additional work to be completed on members of *Quadrula* before splitting the genus (Bogan

2011, pers. comm.). The golden orb is recognized by the Committee on Scientific and Vernacular Names of Mollusks of the Council of Systematic Malacologists, American Malacological Union (Turgeon et al. 1998, p 36), and we recognize it as a valid species.

Habitat/Life History:

The golden orb has been found almost exclusively in flowing waters in moderately sized rivers (Howells 2010a, p. 3). It has been found in only one reservoir in the lower Nueces River (Lake Corpus Christi), where wave action may simulate flowing water conditions (Howells 2010a, p. 3). This species is found in substrates of firm mud, sand, and gravel, and it does not appear to tolerate more unstable substrates such as loose sand or silt (Howells 2002b, p. 6).

There is no specific information on age, or size of maturity for golden orb. However, new research conducted by USGS and the Service on host fish use for central Texas Candidate mussels revealed that golden orb utilizes channel catfish and spotted bass as novel host fish (Johnson et al. 2014, p. 42). The golden orb is a host fish specialist that freely broadcasts its glochidia by reflexive release in the form of mature conglomerates which are usually fragile and tend to disintegrate shortly after release (Johnson et al. 2014, p. 43). Females have been found to carry eggs internally from May through August (Howells 2000b, p. 38). Mussels in the genus *Quadrula* are short-term brooders, which are species that hold fertilized eggs and glochidia for a short period, usually 3 to 6 weeks, before releasing glochidia (Gorden and Layzer 1989, p. 6; Garner et al. 1999, p. 277), and we expect the golden orb to do the same.

Adult freshwater mussels are filter-feeders, siphoning algae, bacteria, detritus, microscopic animals, and dissolved organic matter (Fuller 1974, pp. 221-222, Silverman et al. 1997, p. 1862; Nichols and Garling 2000, p. 874-876; Christian et al. 2004, p. 109). For their first several months, juvenile mussels feed using cilia (fine hairs) on the foot to capture suspended as well as depositional material, such as algae and detritus (Yeager et al. 1994, pp. 253-259). Mussels tend to grow relatively rapidly for the first few years, and then slow appreciably at sexual maturity, when energy presumably is being diverted from growth to reproductive activities (Baird 2000, pp. 66-67). Mussels are extremely long lived, living from two to several decades (Rogers et al. 2001, p. 592), and possibly up to 200 years in extreme instances (Bauer 1992, p. 427).

Most mussel species, including golden orb, have distinct forms of male and female. During reproduction, males release sperm into the water column, which females draw in through their siphons. Fertilization takes place internally, and the resulting eggs develop into specialized larvae (called glochidia) within the female's modified gill pouch (called marsupia) for four to six weeks. The females will then release matured glochidia individually, in small groups, or embedded in larger mucus structures called conglomerates. Glochidia are obligate parasites (cannot live independently of their hosts) on fish and attach to the gills or fins of appropriate host species where they encyst (enclose in a cyst-like structure) and feed off of the host's body fluids (Vaughn and Taylor 1999, p.

913) and develop into juvenile mussels weeks or months after attachment (Arey 1932, pp. 214–215). The glochidia will die if they fail to find the appropriate host fish, attach to a fish that has developed immunity from prior infestations, or attach to the wrong location on a host fish (Neves 1991, p. 254; Bogan 1993, p. 299). Mussels experience their primary opportunity for dispersal and movement within the stream as glochidia attached to a host fish (Smith 1985, p. 105). Upon release from the host, newly transformed juveniles drop to the substrate on the bottom of the stream. Those juveniles that drop in unsuitable substrates die because their immobility prevents them from relocating to more favorable habitat. Juvenile freshwater mussels burrow into interstitial substrates and grow to a larger size that is less susceptible to predation and displacement from high flow events (Yeager et al. 1994, p. 220). Throughout the rest of their life cycle, mussels generally remain within the same small area where they released from the host fish.

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Historical Range/Distribution:

The golden orb is endemic (native) to nearly the entire lengths of the Guadalupe, San Antonio, and Nueces- Frio River basins in central Texas (Howells 2010a, p. 5), including the Guadalupe, Medina, San Antonio, San Marcos, Frio, and Nueces Rivers and Cibolo Creek. It was originally reported from four sites in the Brazos River system (Strecker 1931, p. 63), but these are almost certainly misidentified smooth pimpleback (Howells 2002b, p. 5) based on numerous mussel surveys throughout the Brazos River system since the 1970s that failed to find any golden orb. The species has not been found in studies of archaeological specimens from the Brazos River either (Howells 2010a, p. 5), further indicating golden orb did not historically occur in the Brazos River system. The golden orb has also been reported from the upper Colorado River drainage (Howells et al. 1996, pp. 108–109; Randklev et al. 2010c, p. 4), but these appear to have been misidentified Texas pimpleback (Howells 2010a, p. 5). Since no other golden orbs have been reported from the Colorado River system, we do not believe it occurred in that basin.

Current Range Distribution:

The golden orb has declined significantly rangewide and is now known from only four streams in disjunct locations. Despite mussel surveys across the historical range, since 1995 golden orb has only been found in the Guadalupe, lower San Marcos, lower San Antonio, lower Nueces Rivers and lower Cibolo Creek. The species has been extirpated from the entire Nueces-Frio River basin, except at the extreme downstream end of the Nueces River, where a small population persists just above and within Lake Corpus Christi. Aside from the upper Guadalupe River, all existing populations occur in the lower portion of occupied basins in a small geographical area; about 130 km (80 mi) separate the farthest two populations. Only four populations appear to be relatively stable and recruiting, while the remaining five populations are represented by only a few individuals.

Guadalupe River System

In the Guadalupe River system, the golden orb historically ranged throughout the length of the Guadalupe, San Antonio, and San Marcos Rivers. Currently in this basin, the species only persists in the upper and lower Guadalupe, lower San Marcos, and lower San Antonio Rivers. The lower portion of this basin (within approximately 120 km (75 mi) of the Gulf of Mexico) harbors all four of the large, presumably reproducing populations of golden orb.

Although golden orb were found throughout the mainstem Guadalupe River historically, this species has not been found live or dead, despite repeated surveys, until 1997 (Howells 2002a, p.8; Howells 1994, pp. 7–8; 1996, p. 30; 1997a, p. 36; Howells 1999, p. 18; Howells 2006, p. 71). In 1997, three flood deposited shells were found below the Upper Guadalupe River Authority (UGRA) dam (Howells 1998, p. 18). However, the U.S. Fish and Wildlife Service (Service) and U.S. Geological Survey (USGS), located live and recently dead golden orb and other species in the same general area in 2012 and early 2013 (Service Files 2012; Service Files 2013).

Farther downstream of the UGRA dam, a single recently dead individual was found in 1998 within Louis Hays Park, Kerr County, during an extended drawdown of the river to construct a footbridge in the park (Howells 1999, pp. 18-19; Howells 2006, p. 19). In 2005, two live individuals were also found at this site (Howells 2006, pp. 71–72), showing that the species had survived the drawdown. One live golden orb was found farther downstream near Center Point in Kerr County, and another farther downstream near Comfort in Kendall County during 2011 survey efforts (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev 2012b, pp. 18-19). A total of 29 golden orb were found downstream at two sites in DeWitt County (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev 2012b, pp. 18-19). It is apparent golden orb persists in the mainstem upper Guadalupe River but in low densities.

Subfossil shells (very old shells that are brittle, crumbling, and with extensive erosion) of the Golden orb were found in 1993 (Howells 1995, p. 31), farther downstream in the mainstem Guadalupe River, above Lake Gonzales in Gonzales County. However, the species has not been found in the area since. Below Lake Gonzales, one recently dead individual was collected in 1995 (Howells 1996, pp. 26–27), and 25 live golden orb were recorded at two sites in this area in 1996 (Howells 1997a, pp. 37–38). Later, in 2006, three live golden orb were located in same general area (Howells 2006, pp. 85–86). A small population most likely continues to persist below Lake Gonzales, but in low densities.

A large golden orb population occurs farther downstream in the mainstem Guadalupe River, below Lake Wood dam in Gonzales County. Although none were found during a survey in 1995 (Howells 1996, p. 27), 36 live golden orb were found at two sites below Lake Wood in 1996 (Howells 1997a, pp. 38–40). Surveys in 2002 and 2006 located live golden orbs in the same general area (Howells 2003, p. 11; Howells 1996, pp. 87–91). Additional surveys in 2006 and then in 2008 found 91 and

33 live mussels respectively, indicating that a relatively large population continues to persist in the Guadalupe River downstream of Lake Wood (Burlakova and Karatayev 2008, p. 8; Burlakova and Karatayev 2010a, p. 14). It also contains one of the most abundant freshwater mussel communities in Texas (Burlakova and Karatayev 2008, p.9; Burlakova and Karatayev 2010a, p. 14).

Further downstream in the mainstem of Guadalupe River in Victoria, Victoria County, Texas, a large number of recently dead juveniles were found in 1994. Just below Victoria, Texas, 100 golden orb of multiple size classes, including juveniles, were discovered in 2009 (Johnson 2009, p. 1), indicating that this population was reproducing and recruiting new individuals. In 2012 and 2013, the Service and USGS conducted presence/absence surveys in the same general location and found over 70 live golden orb and several fresh dead to recently dead shells. It is apparent this site continues to harbor a reproducing population of golden orb, as well as an abundant and diverse mussel community (Service Files, 2012; Service Files, 2013).

The San Marcos River, a tributary to the Guadalupe River, has been extensively surveyed over the years and has been found to support large golden orb populations (Howells 1995, pp. 33–34; 1997a, p. 40; 2004, pp. 15–16, 18; 2005, p. 10). Recent surveys in 2011 found several live golden orb near Martindale in Hays County (Johnson and Groce. 2011, p. 10) and downstream near the town of Luling in Caldwell and Guadalupe Counties, 48 additional live individuals were found (TPWD 2014, p. 34). Recently dead shells were also located in Caldwell and Guadalupe counties downstream of the Luling site in 2012 (Service Files, 2012). Further downstream in Caldwell and Gonzales Counties, 23 live golden orb were found in early 2011 (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev 2012b, p. 19). Based on surveys conducted during 2000–2006, 2008–2009, and 2011, populations persist within and downstream of Palmetto State Park in Gonzales County; the downstream site harbors higher densities of golden orb (Howells 2001, pp. 32–33; 2006, pp. 72–73; 2006, p. 91; Burlakova and Karatayev 2010a, pp. 14–15; Burlakova and Karatayev 2012a, p. 19; Burlakova and Karatayev 2012b, pp. 17–20). Live golden orb continue to be found in this section of the river (Service Files, 2012).

Historically, golden orb were numerous in the San Antonio River in Karnes County (OSUM 2011b, p. 1), but only a single subfossil shell was found at each of two sites in Karnes County in 1996 (Howells 1997a, pp. 41–42). San Antonio River Authority conducted a relative mussel abundance, species richness, and habitat utilization analysis in 2011. During this analysis a four mile stretch of river was surveyed extending from Bexar County to Goliad County. Within this stretch, 10 sample reach sites were selected and sampled, and a total of six species, excluding Asian clam (*Corbicula* sp.) were found (Larralde 2011, p. 9). Golden orb was found at all sites and had the highest number of individuals per site totaling 474 out of 894 live mussels found (Larralde 2011, p. 9). The higher densities of golden orb occurred near Goliad County. The lower portion of the San Antonio River supports the largest known golden orb population (Burlakova and Karatayev 2012b, p. 17).

In 2007, 37 live golden orb were recorded near Goliad in Goliad County, both within and

downstream of Goliad State Park (Howells 2009, p. 11). The following year, 285 live golden orb were found within the park and downstream surrounded by private lands (Burlakova and Karatayev 2010a, p. 15; Burlakova and Karatayev 2012b, p. 17). This site represents the largest known population of golden orb. In 2013, the Service and TPWD located 40 live individuals in Goliad County south of Kennedy, Texas (Service Files, 2013). In 2009, a single live golden orb was discovered in the lower San Antonio River south-southwest of Victoria in Victoria County (Johnson 2009, p. 1); this site has not been surveyed since. We presume golden orb may persist in this stretch of river.

The golden orb appears to have been extirpated from the Medina River. The species historically occurred in the Medina River within Medina and Bexar Counties (Randklev et al. 2010b, p. 4; OSUM 2011b, p. 1), but no live or dead mussels of any species have been found in this river in recent years (May 2011, pers. comm.). Burlakova and Karatayev (2012a, pp. 20-21) also stated that they found no live golden orb during their survey efforts of the upper San Antonio River and its tributaries, including Medina River.

Cibolo Creek, a tributary to the San Antonio River, was extensively surveyed in the 1990s, with only old golden orb shells collected in Wilson County (Howells 1995, pp. 35-37; 1997a, pp. 40-41). In 2006 and 2007, Burlakova and Karatayev (2010b, p. 1) surveyed this same general area and found only shell material. However, in 2010, live golden orb were found in Wilson County south of Stockdale, Texas (Robertson 2011, pers. comm.). Because shell material and live individuals have been found at three sites within Wilson County, it is likely this species persists within this water body but in low numbers.

Nueces-Frio River System

Information is limited on the occurrence of golden orb in the Nueces-Frio River system. Other than a population that occurs in a reservoir on the lower Nueces River (Lake Corpus Christi), the species appears to be extirpated from the remainder of the basin.

Historically, the golden orb occurred in the Nueces River in Live Oak County (OSUM 2011b, p. 1). In 1993 and 1995, an unreported number of live individuals and a shell, respectively, were collected in the same general area of Live Oak County (Howells 2010g, p. 1). Additional surveys in 1996 and 1997 found no evidence of the species (Howells 1997a, pp. 43-44; 1998, p. 20). However, recent surveys in McMullen and Live Oak Counties in 2011 found live golden orb at two of the three sites on the mainstem of Nueces River above Lake Corpus Christi.

The site in McMullen County contained no live mussels, but the two sites in Live Oak County harbored 8 live golden orb (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev

2012b, p. 18). We presume the species no longer occurs in the upper portions of the Nueces River and its tributaries, but a very small population continues to persist in a small section of the lower Nueces River just above Corpus Christi Reservoir.

An anomalous (odd) population of golden orb has persisted in Lake Corpus Christi Reservoir in the lower Nueces River. While the species does not typically inhabit lentic (ponded) water, wave action is presumed to simulate flowing water conditions and has supported a golden orb population since at least the 1970s (OSUM 2011b, p. 1). A few live individuals of golden orb have been found within the reservoir consistently since 1994 (Howells 1995, p. 39; 1996, pp. 30–31; Howells 2010g, p. 1). Numbers of golden orb collected increased in 1996, when 86 live golden orb were found at three different locations within the reservoir (Howells 1996, pp. 30–31). However, a drawdown of the lake in 1996 resulted in large numbers of golden orb stranded and killed (Howells 2010a, p. 9), and in 1998 no live individuals were found (Howells 1999, p. 19). Again in 2005, no live individuals were found during surveys, but in 2006, a total of nine were collected at three different sites within the reservoir (Howells 2006, pp. 73–76, 91–93). A small golden orb population likely persists in the reservoir.

Very little information is available on the distribution of golden orb in the Frio River basin. Shells were last seen in McMullen County in 1994 (Howells 2010g, p. 1), but no evidence of the species has been found in this section of the river since (Howells 1995, pp. 37–38; 1996, p. 29; 2002a, pp. 9–10; 2004, pp. 19–20). However, surveys conducted in 2011 suggest otherwise. Three sites were sampled on the Frio River at Canyon Choke Reservoir (McMullen County), in Tilden at State Road 16 (McMullen County), and below Canyon Choke Reservoir in Three Rivers (Live Oak County) (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev 2012b, p. 19). The Frio River above the Canyon Choke Reservoir was dry near Tilden, Texas and was stagnant and polluted west of Fowlerton, La Salle County, Texas (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev 2012b, p. 19). Only three live individuals were found below Canyon Choke Reservoir, in Three Rivers (Live Oak County), Texas (Burlakova and Karatayev 2012a, p. 20; Burlakova and Karatayev 2012b, p. 19). As of 2011, Golden orb persists in the lower Frio River but in very low numbers. It is unknown whether or not this very small population continues to survive the ongoing severe drought.

Population Estimates/Status:

Based on historical and current data, the golden orb has declined rangewide and is now known from only nine populations in four rivers and has been eliminated from nearly the entire Nueces-Frio River system. Four of the nine populations appear to be stable and reproducing; the remaining five populations are small to very small and isolated and show no evidence of recruitment. Only the populations in the middle Guadalupe River and lower San Marcos River are likely connected; the remaining extant populations are highly fragmented and restricted to short reaches.

Threats

A. The present or threatened destruction, modification, or curtailment of its habitat or range:

The decline of mussels in Texas and across the United States is primarily the result of habitat loss and degradation (Neves 1991, pp. 252, 265; Howells et al. 1996, pp. 21–22). Chief among the causes of mussel decline in Texas are the effects of impoundments, sedimentation, dewatering, sand and gravel mining, and chemical contaminants (Neck 1982a, pp. 33–35; Howells et al. 1996, pp. 21–22; Winemiller et al. pp. 17–18). These threats are discussed below.

Impoundments

A major factor in the decline of freshwater mussels across the United States has been the large-scale impoundment of rivers (Vaughn and Taylor 1999, p. 913). Dams are the source of numerous threats to freshwater mussels. They block upstream and downstream movement of species by blocking host fish movement; they eliminate or reduce river flow within impounded areas, thereby trapping silts and causing sediment deposition; they change downstream water flow timing and temperature; decrease habitat heterogeneity; and affect normal flood patterns (Layzer et al. 1993, pp. 68–69; Neves et al. 1997, pp. 63–64; Watters 2000, pp. 261–264; Watters 1996, p. 80). Within reservoirs (the impounded waters behind dams), the decline of freshwater mussels has been attributed to sedimentation, decreased dissolved oxygen, and alteration of resident fish populations (Neves et al. 1997, pp. 63–64; Pringle et al. 2000, pp. 810–815; Watters 2000, pp. 261–264). Dams significantly alter downstream water quality and stream habitats (Allan and Flecker 1993, p. 36; Collier et al. 1996, pp. 1, 7) resulting in negative effects to tailwater (the area downstream of a dam) mussel populations (Layzer et al. 1993, p. 69; Neves et al. 1997, p. 63; Watters 2000, pp. 265–266). Below dams, mussel declines are associated with changes and fluctuation in flow regime, scouring and erosion of stream channels, reduced dissolved oxygen levels and water temperatures, and changes in resident fish assemblages (Williams et al. 1992, p. 7; Layzer et al. 1993, p. 69; Neves et al. 1997, pp. 63–64; Pringle et al. 2000, pp. 810–815; Watters 2000, pp. 265–266). Numerous dams have been constructed throughout the Guadalupe-San Antonio and Nueces-Frio River systems within the range of golden orb (Stanley et al. 1990, p. 61).

Population losses due to the effects of dams and impoundments have likely contributed more to the loss of diversity and abundance of freshwater mussels across Texas, including golden orb, than any other factor. Stream habitat throughout nearly all of the range of golden orb has been affected by numerous impoundments, leaving generally short, isolated patches of remnant habitat between dams. Impoundments have resulted in profound changes to the nature of the rivers, primarily replacing free-flowing river systems with a series of large reservoirs.

There are no natural lakes within the range of the golden orb; however, it does occur in one impoundment, Lake Corpus Christi, indicating that inundation may not be as detrimental to this species as it is to other, more flow-dependent mussel species. However, this particular population is located in sections of the reservoir that are windswept simulating flowing waters.

Impoundments occur throughout the range of the golden orb. The majority of the Nueces-Frio,

Guadalupe-San Antonio, Colorado, and Brazos Rivers, as well as many tributaries, are now impounded. There are 29 reservoirs, each with a storage capacity of 3,000 acre-feet or more, within the Guadalupe River basin and 34 within the San Antonio River basin, in addition to many other smaller reservoirs in these basins (Exelon 2010, p. 2.3–4). Three large reservoirs exist within the Nueces River basin. The majority of the large dams were constructed for power generation, flood control, and water supply, primarily by the Guadalupe-Blanco River Authorities, beginning in the early twentieth century (Guadalupe-Blanco River Authority 2011, p. 1). These and numerous smaller dams occur throughout the Guadalupe-San Antonio and Nueces-Frio River basins and have resulted in ongoing destruction and modification of golden orb habitat and the curtailment of its range.

Dams threaten freshwater mussels in several ways. First, they can prevent the movement of freshwater mussel host fish. The overall distribution of mussels is a function of the dispersal of their hosts (Watters 1996, p. 83). For example, Watters (1996, p. 80) found that the distributions of the fragile papershell (*Leptodea fragilis*) and pink heelsplitter (*Potamilus alatus*) in five midwestern rivers were determined by the presence of low-head dams. These dams were non-navigable (without locks), lacked fish ladders, and varied in height from 1 to 17.7 m (3 ft to 58 ft), and the host fish could not disperse through them. Although the distribution of mussels may depend on many ecological factors, the evidence presented in Watters (1996, pp. 79–85) illustrates that dams as small as 1 m (3 ft) high can limit the distribution of mussels. There are many dams that occur throughout the range of the golden orb that lack fish ladders and may be a barrier to the movement of fish hosts and, therefore, the distribution of mussels. Because the golden orb populations are all separated by dams of various sizes that are not passable by fish, the mussel is unable to disperse from its current occupied range through host fish migration.

Dams also alter aquatic habitat within the resulting impoundments. It is well documented that many mussel species that are adapted to flowing water stream environments do poorly in the altered aquatic conditions found within impoundments (Williams et al. 1992, p. 7; Vaughn and Taylor 1999, p. 913). Once a dam is constructed, the original river channel upstream remains intact but under much deeper water with much lower velocities. As water velocity decreases, water loses its ability to carry sediment; sediment falls to the substrate, eventually smothering mussels that cannot adapt to soft substrates (Watters 2000, p. 263). Over time, the original mussel species composition of the stream channel may be eliminated or changed in favor of silt tolerant species (Watters 2000, p. 264). The mussel community may be altered from one with many different species to a community dominated by one to several very common species (Neck 1982b, p. 174). For example, seven Texas native freshwater mussel species, including the golden orb, were lost due to the impoundment on the Medina River (Neck 1989, p. 323). The Medina River was impounded in 1913 by construction of Medina Dam, and now only three different species of mussels, all of which are tolerant of lentic habitats, occur in the impounded area. The bottom of Medina Lake now consists of moderate and steep limestone slopes and excessive silt deposits, whereas before it was most likely made up of a combination of silt, sand, and gravel substrates. Most mussels native to the Medina River were unable to adapt to the change in flowing water and substrate conditions (Neck 1989, p. 323), including the golden orb, which is no longer found in the river. The inundation of stream habitat by impoundments is likely one of the causes of the reduction in the distribution of the golden orb. The presence of the impoundments has caused the permanent loss of golden orb habitat throughout its range. However, there is one anomalous population of golden orb that has persisted

in Lake Corpus Christi Reservoir since the 1970s (OSUM 2011b, p. 1). While the species does not typically inhabit lentic water, wave action is presumed to simulate flowing water conditions and has supported what was once a large population of golden orb.

For species such as golden orb that may be able to survive the initial inundation of reservoirs, conditions within the reservoir are likely to become uninhabitable. The deep water in reservoirs is very cold and often devoid of oxygen and necessary nutrients (Watters 2000, p. 264). Cold water (less than 11 °C (52 °F)) has been shown to stunt mussel growth (Hanson et al. 1988, p. 352). Because mussel reproduction is temperature dependent (Watters and O'Dee 1999, p. 455), it is likely that individuals living in the constantly cold hypolimnion in these channels may never reproduce, or reproduce less frequently (Watters 2000, p. 264). Any golden orb that survived the initial inundation may have been unable to reproduce, eventually eliminating the species from large areas of the reservoir. The same would be true for mussels living in cold-water discharges downstream of large impoundments (Watters 2000, p. 264).

In addition, mussels downstream of impoundments are often affected through changes in fish host availability, water quality (particularly lower water temperatures), habitat structure, and stream channel scouring (Vaughn and Taylor 1999, p. 916). The release of cold water from the hypolimnion (deeper and colder layer of water in reservoirs) can decrease the occurrence of fish species adapted to warm water and increase the occurrence of fish species adapted to colder water (Edwards 1978, pp. 73–75). This changes the species composition of suitable host fish and may prevent mussels from completing an essential part of their reproductive cycle. This has been demonstrated by the extirpation of mussel species from several rivers on the eastern seaboard of the United States, which has been linked to the disappearance of appropriate host fish; the reintroduction of the host fish to rivers has enabled mussel species to recolonize areas (Kat and Davis 1984, p. 174). In addition, because mussel reproduction is temperature dependent (Watters and O'Dee 1999, pp. 455–456), it is likely that individual mussels living in cold waters downstream of dam releases may reproduce less frequently, if at all (Layzer et al. 1993, p. 69). Low water temperatures can also significantly delay or prevent metamorphosis and glochidial release, which is often triggered by water temperature (Watters and O'Dee 1999, pp. 454–455; Watters and O'Dee 2000, p. 136).

Similar changes in water temperatures downstream of dams may be responsible for the loss of some golden orb populations. For example, historical records showed that the golden orb once occurred in the Guadalupe River in Comal County before the Canyon Reservoir was constructed in 1964 (Randklev et al. 2010c, p. 4). Temperature monitoring stations throughout the Guadalupe River basin show that maximum temperatures above Canyon Reservoir averaged 29.6 degrees Celsius (°C) (85.3 degrees Fahrenheit (°F)); the maximum stream temperatures below the reservoir averaged only 19.7 °C (67.5 °F) (Edwards 1978, p. 72). After impoundment, dissolved oxygen and water temperature dropped, with an accompanying drop in mussel numbers and species diversity (Young et al. 1976, p. 216). According to historical museum records analyzed by Randklev et al. (2010b, pp. 1–32), the golden orb once occurred in this area of the Guadalupe River prior to the construction of Canyon Reservoir. No live or recently dead golden orb have been found in this reach since the reservoir was completed (Burlakova and Karatayev 2010a, pp. 14–15), and we presume the species is extirpated from this reach because of the effects of the reservoir. Surveys of the reservoirs in the Guadalupe River system have been ongoing since at least 1992, and no evidence of live or dead golden orb has been found in any of the reservoirs (Howells 1994, pp.

1–20; 1995, pp. 1–50; 1996, pp. 1–45; 1997a, pp. 1–58; 1998, pp. 1–30; 1999, pp. 1–34; 2000a, pp. 1–56; 2001, pp. 1–50; 2002a, pp. 1–28; 2003, pp. 1–42; 2004, pp. 1–48; 2005, pp. 1–23; 2006, pp. 1–106; Karatayev and Burlakova 2008, pp. 1–47; Burlakova and Karatayev 2010a, pp. 1–30; 2011, pp. 1–8).

In addition to the temperature of water released from dams, highly fluctuating, turbulent tailwaters devoid of sediment will scour the riverbed downstream of dams, rendering the area without mussel habitat (Layzer et al. 1993, p. 69). Depending on the use of the dam, water levels may fluctuate on a regular interval (for hydroelectric purposes) or at random (for flood control) (Watters 2000, p. 265). In the Guadalupe River basin, Canyon Lake, Gonzales Lake, and Lake Medina are each used for one or both of these purposes. Mortality of another rare mussel species in Texas, the Texas heelsplitter (*Potamilus amphichaenus*), was attributed to scheduled dewatering of the Neches River below B.A. Steinhagen Reservoir in east Texas (Neck and Howells 1994, p. 15). Fluctuating water levels below dams also result in dramatic changes in water velocity. Downstream of Lake Livingston on the Trinity River in east Texas, for example, high-volume water discharges and abrupt stoppages of flow resulted in a river bed composed of large rocks and shifting sand (Neck and Howells 1994, p. 14); these kinds of habitat changes would be inhospitable to golden orb below the dams within its range. In some rivers this unstable zone may be extensive. For example, on the Brazos River downstream of Possum Kingdom Reservoir in Texas exhibited unstable substrate for 150 km (240 mi) below the dam (Yeager 1993, p. 68).

In one study of the downstream effects of dams, Vaughn and Taylor (1999, p. 915) found a strong, gradual, linear increase in mussel species richness and abundance at sites on the Little River in Oklahoma downstream from Pine Creek Reservoir. Their research revealed that mussel species richness and total abundance did not begin to rebound until 20 km (12 mi) downstream of the impoundment and did not peak until 53 km (33 mi) downstream. They noted the most obvious difference since reservoir construction has been the alteration of the flow and temperature regimes, which gradually return to preimpoundment levels with downstream distance from the dam. These alterations appear to have produced an extinction gradient of mussels that is most severe near the dam (Vaughn and Taylor 1999, p. 915). We expect similar effects on the golden orb and other Texas mussels downstream of dams.

In one area on the Guadalupe River in Kerr County, a golden orb population once existed directly below a small dam (Howells 1997a, p. 36), indicating the effects of the dam construction and closure were not immediately lethal. However, the population has been presumed extirpated since 1998 (Howells 2006, p. 71), and it is likely that fluctuating downstream flows from the dam contributed to the loss of this population.

Dam construction also fragments the range of golden orb, leaving remaining habitats and populations isolated by the structures, as well as by extensive areas of deep, uninhabitable, impounded waters. These isolated populations are unable to naturally recolonize suitable habitat that may be impacted by temporary but devastating events, such as severe drought, chemical spills, or unauthorized discharges. Dams impound river habitats throughout almost the entire range of the species. These impoundments have left short and isolated patches of remnant habitat, typically in between impounded reaches, such as the golden orb population on the Guadalupe River within about 1.6 km (1 mile) downstream of Lake Wood. This population is subject to dramatic flow fluctuations from the hydroelectric facility associated with the dam (Howells 2010a, p. 4), which can leave individuals stranded when water levels are quickly lowered or wash individuals

downstream when flow is increased.

The widespread construction of dams throughout the range of golden orb has significantly altered stream habitat both upstream and downstream of the dams by changing fish assemblages, temperature, dissolved oxygen, and substrate. The effects of dams on the golden orb are expected to be ongoing decades after construction and are presumed to be continuing today. Because of this loss of habitat and its widespread effects on the populations, we conclude that the effects of dams are a threat to the golden orb.

Sedimentation

Siltation and general sediment runoff is a pervasive problem in streams and has been implicated in the decline of stream mussel populations (Ellis 1936, pp. 39–40; Vannote and Minshall 1982, p. 4105; Dennis 1984, p. ii; Brim Box and Mossa 1999, p. 99; Fraley and Ahlstedt 2000, pp. 193–194). Specific biological effects on mussels from excessive sediment include reduced feeding and respiratory efficiency from clogged gills (Ellis 1936, p. 40), disrupted metabolic processes, reduced growth rates, increased substrate instability, limited burrowing activity (Marking and Bills 1979, pp. 208–209; Vannote and Minshall 1982, p. 4106), physical smothering, and disrupted host fish attractant mechanisms (Hartfield and Hartfield 1996, p. 373). The primary effects of excess sediment on mussels are sublethal, with detrimental effects not immediately apparent (Brim Box and Mossa 1999, p. 101).

The physical effects of sediment on mussel habitats are multifold and include changes in suspended material load; changes in streambed sediment composition from increased sediment production and runoff in the watershed; changes in the form, position, and stability of stream channels; changes in water depth or the width-to-depth ratio, which affects light penetration and flow regime; actively aggrading (filling) or degrading (scouring) channels; and changes in channel position that may leave mussels stranded (Brim Box and Mossa 1999, pp. 109–112).

Increased sedimentation and siltation may explain, in part, why golden orb appear to be experiencing recruitment failure in some streams. Interstitial spaces (small openings between rocks and gravels) in the substrate provide essential habitat for juvenile mussels. When clogged with sand or silt, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999, p. 100), thus reducing juvenile habitat availability. Juvenile freshwater mussels, including golden orb juveniles, burrow into interstitial substrates, making it particularly susceptible to degradation of this habitat.

Even in 1959, the Guadalupe River was noted as having high sedimentation rates from agricultural activities (Soil Conservation Service 1959, p. 59). Sedimentation can occur from agricultural activities, sand and gravel mining, urban runoff, and construction activities, among other sources. Approximately 40 percent of U.S. river miles do not meet Clean Water Act standards due to excessive sediment loads (Environmental Protection Agency (EPA) 2000, p. 1), with agricultural activities being the primary source of sediment in streams (Waters 1995, p. 170). In general, sedimentation, resulting from unrestricted access by livestock, has been shown to be a significant threat to many streams and their mussel populations (Fraley and Ahlstedt 2000, p. 193). A primary land use throughout the range of the golden orb is grazing by cattle, sheep, and goats (Hersh 2007, p. 11). Soil compaction, which reduces vegetative growth, from intensive grazing, may reduce infiltration rates and increase runoff and erosion, and trampling of riparian vegetation increases the probability of erosion (Armour et al. 1994, p.10; Brim Box and Mossa 1999, p. 103). Turbidity has also been recorded as high in the Guadalupe River near Victoria (Exelon 2010, p. 2.3–186),

indicating a large amount of suspended sediment where a small population of golden orb was recently found.

Sedimentation may become an increasing threat to the golden orb in the Guadalupe River basin as the San Antonio metro area continues to expand. Activities associated with urbanization, such as road construction, increased impervious surfaces, and road construction can be detrimental to stream habitats (Couch and Hamilton 2002, p. 1), and the City of San Antonio, the second largest city in Texas, continues to grow (City of San Antonio 2010, p. 5). Runoff from increased impervious surfaces increases sediment loads in streams and destabilizes stream channels (Pappas et al. 2008, p. 151). Impervious surfaces also result in channel instability by accelerating stormwater runoff, which increases bank erosion and bed scouring, thereby further increasing downstream sedimentation (Brim Box and Mossa 1999, p. 103). While erosion and sedimentation associated with road construction may be temporary, the existence of road crossings is shown to have ongoing impacts to mussel habitat. For example, in the Guadalupe River, road crossings were found to cause a long-term increase in sedimentation both upstream and downstream, as channel constriction reduced flow upstream, causing sediment deposition, and runoff from the road increased sedimentation downstream (Keen- Zebert and Curran 2009, p. 301). Urban development activities may also affect streams and their mussel fauna where adequate streamside buffers are not maintained and erosion from adjacent land is allowed to enter streams (Brainwood et al. 2006, p. 511).

Large projects that reduce vegetative cover within the watersheds supporting golden orb populations can also increase sedimentation flowing into streams. For example, the Lower Colorado River Authority Transmission Services Corporation (LCRA TSC) is proposing to construct two new 345- kilovolt (kV) electric transmission line facilities between Tom Green (in the Colorado River basin near San Angelo) and Kendall Counties (in the Guadalupe River basin north of San Antonio) to provide electrical power to accommodate increased human populations (Clary 2010, p. 1). One of the proposed transmission lines would cross the upper Guadalupe River in Kerr County, which contains a small population of golden orb. The proposed project could negatively affect golden orb habitat if construction or maintenance of the transmission line requires removal of vegetation within the riparian zone and that removal results in an increase in sediment runoff into the Guadalupe River (Clary 2010, pp. 7, 9, 15). Similar infrastructure development activities to accommodate Texas population growth are expected to be undertaken across the species' range and will likely lead to additional sources of sediment in the streams inhabited by the golden orb. Streams occupied by golden orb are subject to increasing levels of sedimentation from agricultural activities, instream sand and gravel mining (discussed in section titled Sand and Gravel Mining), vegetation removal, and urbanization. All of these activities are ongoing throughout the range of the golden orb and are unlikely to decrease, resulting in significant threats to the golden orb.

Dewatering

River dewatering can occur in several ways: Anthropogenic activities such as surface water diversions and groundwater pumping, and natural events, such as drought. Surface water diversions and groundwater pumping can lower water tables, reducing river flows and reservoir levels. When water levels in streams and reservoirs are lowered dramatically, it can result in mussels being stranded and dying in previously wetted areas. This is a particular concern within and below reservoirs where water levels are managed for purposes that result in water levels in the reservoir or downstream to rise or fall in very short periods of time, such as when hydropower

facilities release water during peak energy demand periods. For example, Lake Corpus Christi reservoir has experienced several drawdowns of lake levels to reduce salinity levels in the reservoir, such as in 1996 and 2006. Golden orb have been stranded above the water line during both drawdowns, killing the exposed mussels (Howells 2006, pp. 75–76). Rivers can also be dewatered to facilitate construction activities, such as in the upper Guadalupe River in Kerr County, which was dewatered in 1998 for bridge construction, which exposed and killed golden orb (Howells 1999, pp. 18–19).

Drought can also severely impact golden orb populations. Central Texas, including the Guadalupe River basin, experienced a major drought in the late 1970s (Lewis and Oliveria 1979, p. 243). Near record dry conditions in 2008 followed by a pattern of below-normal rainfall during the winter and spring of 2009 led to one of the worst droughts in recorded history for most of central Texas, including the range of the golden orb (Nielsen-Gammon and McRoberts 2009, p. 2). This drought's severity was exacerbated by abnormally high air temperatures, a likely effect of climate change, which has already increased average air temperatures in Texas by at least 1 °C (1.8 °F) (Nielsen-Gammon and McRoberts 2009, p. 22). The Guadalupe River in Kerr County experienced minimal to no flow during periods of the 2009 drought (USGS 2011b, p. 2), which may have negatively affected this golden orb population. Central Texas is currently experiencing another extreme drought, with rainfall between October 2010 and July 2011 being the lowest on record during those months (LCRA 2011c, p. 1); the effects of this drought are being observed but are not yet fully known. As low flows persist, mussels face oxygen deprivation, increased water temperature, and, ultimately, stranding (Golladay et al. 2004, p. 501).

According to the National Weather Service records for 2011, more than 77 percent of Texas is experiencing moderate to extreme drought (Burlakova and Karatayev 2012b, p. 16). Current climate model simulations suggest that the American southwest could experience a 60-year stretch of heat and drought unseen since the 12th century and that the region is likely to become drier and experience more frequent droughts, with changes accelerating toward the end of the century (Woodhouse et al. 2010, pp. 21283-21288). Droughts result in a decrease in water depth and flow velocity, which reduces food and oxygen delivery. As droughts persist, mussels face hypoxia, elevated water temperature and, ultimately, stranding (Golladay et al. 2004, p. 501).

We do not know the extent of the impacts of stream dewatering on the golden orb; however, because this species' populations are small and isolated, the loss of numerous individuals at a site can have dramatic consequences to the population. Hydropower facilities, construction, surface water diversions, groundwater pumping, and drought are occurring throughout the range of the golden orb; therefore, the effects of dewatering are ongoing and unlikely to decrease in the future, resulting in significant threats to the golden orb.

Sand and Gravel Mining

Sand and gravel mining (removing bed materials from streams) has been implicated in the destruction of mussel populations across the United States (Hartfield 1993, pp. 136–138). Sand and gravel mining causes stream instability by increasing erosion and turbidity (a measure of water clarity) and causing subsequent sediment deposition downstream (Meador and Layher 1998, pp. 8–9). These changes to the stream can result in large-scale changes to aquatic fauna, by altering habitat and affecting spawning of fish, mussels, and other aquatic species (Kanehl and Lyons 1992, pp. 4–11).

Sedimentation and increased turbidity can accrue from instream mining activities. In the Brazos

River, a gravel dredging operation was documented as depositing sediment as far as 1.6 km (1 mi) downstream (Forshage and Carter 1973, p. 697). Accelerated streambank erosion and downcutting of streambeds are common effects of instream sand and gravel mining, as is the mobilization of fine sediments during sand and gravel extraction (Roell 1999, p. 7).

Mining activities may threaten some local golden orb populations. In 1995, the reach of the Guadalupe River near Victoria, which contains a golden orb population, was described as having numerous current and abandoned sand and gravel mining areas (USACE 1995, p. 7). Currently, TPWD has permitted one sand mining activity within the existing range of golden orb, in the Guadalupe River basin in Comal County (TPWD 2009b, p. 1). Golden orb populations occur upstream and downstream of this area in the Guadalupe River. The permit allows for the repeated removal of sand and gravel at various locations within the stream.

In areas where repeated mining occurs, an upstream progression of channel degradation and erosion (called headcutting) can occur (Meador and Layher 1998, p. 8). Headcutting may move miles upstream in a zipper-like fashion as the upper boundary of the modified area collapses. Headcutting can be found within the majority of rivers and streams in Texas, including within the golden orb's current and historical range (Kennon et al. 1967, p. 22). Headcuts induced by sand and gravel mining can cause dramatic changes in streambank and channel shape that may affect instream flow, water chemistry and temperature, bank stability, and siltation (Meador and Layher 1998, p. 8), all of which are harmful to freshwater mussels. Mussels are particularly vulnerable to channel degradation and sedimentation processes associated with headcutting due to their immobility (Pringle 1997, p. 429).

Headcuts from sand and gravel mining operations have been documented in the San Antonio River basin in Karnes County from as early as 1967, with downstream channels having steep, eroded banks (Kennon et al. 1967, p. 22). The golden orb has not been documented from this area since 1996, and only an old, eroded shell was collected at that time (Howells 1997a, pp. 41–42).

In addition to headcutting, mines that are located near stream channels are subject to the gravel pit being captured by the stream during flood events or due to gradual channel migration (Simmang and Curran 2006, p. 1). For example, two gravel mines along the Colorado River downstream of Austin were inundated; one by stream channel migration in 1984, one by stream capture in 1991 (Simmang and Curran 2006, p. 1). Once captured by the mainstem river, gravel mines contribute large amounts of suspended sediment to the river, causing additional turbidity and sedimentation and further degrading mussel habitat.

The golden orb populations in the Guadalupe River may be currently threatened by sand and gravel mining. These activities occur over a long period of time, destabilizing habitat both upstream and downstream, which decreases the likelihood of recolonization after the activity has been completed. Therefore, the effects of sand and gravel mining are an ongoing threat to the golden orb.

Chemical Contaminants

Chemical contaminants are ubiquitous throughout the environment and are a major reason for the decline of freshwater mussel species nationwide (Richter et al. 1997, p. 1081; Strayer et al. 2004, p. 436; Wang et al. 2007a, p. 2029). Chemicals enter the environment through both point and nonpoint discharges, including spills, industrial sources, municipal effluents, and agriculture runoff. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. As a result, water quality can

be degraded to the extent that mussel populations are adversely affected.

Chemical and oil spills can be especially devastating to mussels because they may result in exposure of a relatively immobile species to elevated concentrations that far exceed toxic levels. Acute and chronic exposure to oil spills in freshwater systems is largely understudied; therefore, little information is available on effects of oil spills on freshwater ecosystems (Harrel 1985, p. 223; Bhattacharyya et al. 2002, p. 205). Oil is retained much longer in marshes and other low-energy environments, such as slow-moving streams and rivers, than on wave-swept coasts (Bhattacharyya et al. 2002, p. 205). Oils have been found in sediments at low energy sites as much as 5 years after the occurrence of spills, and they may be released into the water column long after the initial spill. Oil may have various chronic effects on water-column and benthic (bottom-dwelling) species. These effects include sensory disruption, behavioral and developmental abnormalities, and reduced fertility (Bhattacharyya et al. 2002, p. 205). Oil spilled on the water surface may also limit oxygen exchange, coat the gills of aquatic organisms, and cause pathological lesions on respiratory surfaces, thereby affecting respiration in aquatic organisms. Effects of oil on freshwater mussels may result from oil settling on the sediment surfaces and accumulating in the sediment. This can prevent invertebrate colonization (Bhattacharyya et al. 2002, p. 205). Complete recovery of benthic communities may be a matter of years, with communities in the meantime consisting solely of pollutant-tolerant organisms (Bhattacharyya et al. 2002, p. 205). Oil spills can occur from on-site accidents (tank, pipeline spills) or from tanker truck accidents within watersheds occupied by golden orb. For example, 450 gallons of oil were spilled into Lake Bastrop, a reservoir on a tributary to the Colorado River, in February 2011 (Cihock 2011, p. 1).

Exposure of mussels to persistent low concentrations of contaminants likely to be found in aquatic environments can also adversely affect mussels and their populations. Such concentrations may not be immediately lethal, but over time can result in mortality, reduced filtration efficiency, reduced growth, decreased reproduction, changes in enzyme activity, and behavioral changes to all mussel life stages (Naimo 1995, pp. 351–352; Baun et al. 2008, p. 392). Frequently, procedures that evaluate the “safe” concentration of an environmental contaminant (for example, national water quality criteria) do not have data for freshwater mussel species or do not consider data that are available for freshwater mussels (March et al. 2007, pp. 2066–2067, 2073).

One chemical that is particularly toxic to early life stages of mussels is ammonia. Sources of ammonia include agricultural activities (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste (Augspurger et al. 2007, p. 2026), as well as precipitation and natural processes (decomposition of organic nitrogen) (Goudreau et al. 1993, p. 212; Hickey and Martin 1999, p. 44; Augspurger et al. 2003, p. 2569; Newton 2003, p. 2543). Therefore, ammonia is considered a limiting factor for survival and recovery of some mussel species due to its ubiquity in aquatic environments, high level of toxicity, and because the highest concentrations typically occur in mussel microhabitats (Augspurger et al. 2003, p. 2574).

In addition, studies have shown that ammonia concentrations increase with increasing temperature and low-flow conditions (Cherry et al. 2005, p. 378; Cooper et al. 2005, p. 381), which may be exacerbated during low-flow events in streams. Within the range of golden orb, high ammonia levels are common, either chronically, such as in Elm Creek, which is listed as impaired due to high ammonia concentrations (Texas Commission on Environmental Quality (TCEQ) 2010a, p. 294), or due to spills. A wastewater leak in August 2010 spilled approximately 380,000 liters (L) (100,000 gallons (gal)) of sewage into Elm Creek (Bramlette and Cosel 2010, p. 1); ammonia is present in

high concentrations in sewage, among other pollutants. Additionally, a sewage spill in 2008 in Onion Creek discharged nearly 380,000 L (100,000 gal), and another sewage spill occurred in April 2011 in Quinlan Creek, a tributary to the Guadalupe River near the Kerr County population (MacCormack 2011, p. 1). High ammonia levels from chronic sources as well as from spills may be affecting golden orb populations.

In addition to ammonia, agricultural sources of chemical contaminants include two broad categories that have the potential to adversely affect mussel species: Nutrients and pesticides. High amounts of nutrients, such as nitrogen and phosphorus, in streams can stimulate excessive plant growth (algae and periphyton, among others), which in turn can reduce dissolved oxygen levels when dead plant material decomposes. Nutrient over-enrichment in streams is primarily a result of runoff of fertilizer and animal manure from livestock farms, feedlots, and heavily fertilized row crops (Peterjohn and Correll 1984, p. 1471). Over-enriched conditions are exacerbated by low-flow stream conditions, such as those experienced during typical summer season flows. Bauer (1988, p. 244) found that excessive nitrogen concentrations can be detrimental to the adult freshwater pearl mussel (*Margaritifera margaritifera*), as was evident by the positive linear relationship between mortality and nitrate concentrations. Also, a study of mussel life span and size (Bauer 1992, p. 425) showed a negative correlation between growth rate and high nutrient concentrations, and longevity was reduced as the concentration of nitrates increased. Juvenile mussels in interstitial habitats are particularly affected by depleted dissolved oxygen levels resulting from nutrient over-enrichment (Sparks and Strayer 1998, p. 133). The golden orb occurs within the Concho River watershed, which has been documented as having particularly high nitrates for nearly 20 years, likely due to intensive agriculture in the area (Texas Clean Rivers Program 2008, p. 2), which may be affecting the golden orb population.

Mussels are also affected by metals, such as cadmium, chromium, copper, mercury, and zinc, which can negatively affect biological processes such as growth, filtration efficiency, enzyme activity, valve closure, and behavior (Keller and Zam 1991, p. 543; Naimo 1995, pp. 351–355; Jacobson et al. 1997, p. 2390; Valenti et al. 2005, p. 1244). Metals occur in industrial and wastewater effluents and are often a result of atmospheric deposition from industrial processes and incinerators. Studies have shown that copper can have toxic effects on glochidia and juvenile freshwater mussels (Wang et al. 2007a, pp. 2036–2047; Wang et al. 2007b, pp. 2048–2056). In the range of golden orb, high copper concentrations have been recorded in fish in the lower Guadalupe River and San Antonio River (Lee and Schultz 1994, p. 8). While these high levels of copper in fish are not directly informative of the level of copper within the habitat of the golden orb, these observations demonstrate that copper levels are likely high in the lower Guadalupe and San Antonio Rivers. Because we know that copper contamination in water can lead to death of mussels, we conclude that the copper may be adversely affecting golden orb.

Mercury is another heavy metal that has the potential to negatively affect mussel populations, and it is widely distributed in the environment. Mercury has been detected throughout aquatic environments as a product of municipal and industrial waste and atmospheric deposition from coal burning plants. Rainbow mussel (*Villosa iris*) glochidia have been demonstrated to be more sensitive to mercury than juvenile mussels, with the median lethal concentration value of 14 parts per billion (ppb) for glochidia, compared to 114 ppb for the juvenile life stages (Valenti 2005, p. 1242). The chronic toxicity tests conducted determined that juveniles exposed to mercury greater than or equal to 8 ppb exhibited reduced growth. Acute mercury toxicity was determined to be the

cause of extirpation of a diverse mussel community for a 112 km (70 mi) portion of the North Fork Holston River in Virginia (Brown et al. 2005, pp. 1455–1457). Mercury has been documented throughout Texas rivers, with particularly high concentrations in fish in the upper reaches of some of the rivers (Lee and Schultz 1994, p. 8). As with copper, we do not have information on the concentration of mercury that golden orb is being exposed to in these streams, but the higher than expected levels in fish indicate high mercury levels in the area, which may be adversely affecting golden orb.

Pesticides are another source of contaminants in streams. Elevated concentrations of pesticides frequently occur in streams due to pesticide runoff, overspray application to row crops, and lack of adequate riparian buffers. The timing of agricultural pesticide applications in the spring often coincides with the reproductive and early life stages of mussels, which may increase the vulnerability of mussels to pesticides (Bringolf et al. 2007a, p. 2094). Little is known regarding the effect of currently used pesticides to freshwater mussels even though some pesticides, such as glyphosate (active ingredient in Roundup®), are used globally. Recent studies tested the toxicity of glyphosate, its formulations, and a surfactant (MON 0810) used in several glyphosate formulations, to early life stages of the fatmucket (*Lampsilis siliquoidea*) (Bringolf et al. 2007a, p. 2094). Studies conducted with fatmucket juveniles and glochidia determined that the surfactant was the most toxic of the compounds tested and that fatmucket glochidia were the most sensitive organisms tested to date (Bringolf et al. 2007a, p. 2094). Roundup®, technical grade glyphosate isopropylamine salt, and isopropylamine were also acutely toxic to juveniles and glochidia (Bringolf et al. 2007a, p. 2097). These commonly applied pesticides may be adversely affecting golden orb populations. The effects of other widely used pesticides, including atrazine, chlorpyrifos, and permethrin, on glochidia and juvenile life stages have also recently been studied (Bringolf et al. 2007b, p. 2101). Environmentally relevant concentrations (concentrations that may be found in streams) of permethrin and chlorpyrifos were found to be toxic to glochidia and juvenile fatmucket (Bringolf et al. 2007b, pp. 2104–2106). Commonly applied pesticides are a threat to mussels as a result of their widespread use. All of these pesticides are commonly used on agricultural lands throughout the range of the golden orb, which may be adversely affecting the species.

A potential, but undocumented, threat to freshwater mussels, including golden orb, are compounds referred to as “emerging contaminants” that are being detected in aquatic ecosystems at an increasing rate. These include pharmaceuticals, hormones, and other organic contaminants that have been detected downstream from urban areas and livestock production (Kolpin et al. 2002, p. 1202) and have been shown to affect fish behavior (TCEQ 2010b, p. 3). In samples of the Trinity River, for example, compounds such as antidepressants, antihistamines, blood pressure lowering medication, antiseizure medication, and antimicrobial compounds were all detected during a 2006 study (TCEQ 2010b, pp. 27–28). A large potential source of these emerging contaminants is wastewater being discharged through both permitted (National Pollutant Discharge Elimination System (NPDES)) and nonpermitted sites within the Colorado and Guadalupe River systems. Although streams within the range of golden orb have not been tested for these emerging contaminants, permitted discharge sites are ubiquitous in watersheds with golden orb populations, providing many opportunities for contaminants to impact the species.

A study in the Blanco River found that mussels may be adversely affected by sewage effluent (Horne and McIntosh 1979, p. 132). Ammonia levels below the outfall were three times higher than the levels above the outfall and were higher than recently determined toxicity values of ammonia

for mussels (Augsperger et al. 2003, p. 2572). The river was nutrient-enriched for miles downstream, and mussels were less abundant below the outfall than above (Horne and McIntosh 1979, pp. 124– 125, 132).

Texas Commission on Environmental Quality (TCEQ) data for 2010 indicated the majority of the assessed water bodies within the golden orb's historical and current range did not meet surface water quality standards and were classified as impaired water bodies (Nueces River Authority 2010, pp. 1–37; Texas Clean Rivers Program 2010b, p. 13). These water bodies were impaired with dissolved solids, nitrates, bacteria, low dissolved oxygen, sulfates, phosphates, chloride, chlorophyll-a, and low pH associated with agricultural, urban, municipal, and industrial runoff. Of these, nitrates and low dissolved oxygen pose the greatest threat to the golden orb. Additionally, several streams within the range of the golden orb have been listed as impaired due to high ammonia concentrations, including Elm Creek in the Guadalupe River basin (TCEQ 2010a, p. 294). High copper concentrations have been recorded in the lower Guadalupe and San Antonio Rivers (Lee and Schultz 1994, p. 8), and mercury has been documented throughout the Guadalupe and San Antonio Rivers, with particularly high concentrations found in fish tissues from the upper reaches of both rivers (Lee and Schultz 1994, p. 8). Row crop agriculture and wastewater discharges are prominent within the range of the golden orb. These activities result in chronic contamination from agricultural pesticides and emerging contaminants of rivers inhabited by the species and are a threat to golden orb.

Numerous spills of potential contaminant materials have occurred within the range of the golden orb. These can occur from on site accidents (tank, pipeline spills) or from tanker truck accidents within watersheds occupied by golden orb. For example, 100,000 gallons of sewage spilled into the San Antonio River near the City of San Antonio when a pipeline collapsed in October 2010 (San Antonio Water System 2010, p. 1). The largest known golden orb population occurs downstream of this location. Raw sewage contains very high ammonia levels, which is toxic to freshwater mussels, as well as other pollutants. Additionally, 300 gallons of diesel fuel spilled into the San Antonio River near the same location in May 2011 (Serna 2011, p. 1). Another sewage spill occurred in April 2011 in Quinlan Creek, a tributary to the Guadalupe River near the Kerr County population of golden orb (MacCormack 2011, p. 1). The actual effects on the golden orb of spills such as these recent examples are unknown, but there are likely to be negative consequences.

Because of the risk of spills as well as chronic contamination, chemical contaminants, such as oil, ammonia, copper, mercury, nutrients, pesticides, and other compounds are currently a threat to the golden orb. The species is vulnerable to acute contamination from spills as well as chronic contaminant exposure, which is occurring rangewide.

Summary of Factor A

The reduction in numbers and range of the golden orb is primarily the result of the long-lasting effects of habitat alterations such as the effects of impoundments, sedimentation, dewatering, sand and gravel mining, and chemical contaminants. Impoundments occur throughout the range of the species and have farreaching effects both up- and downstream. Both the Colorado and Guadalupe River systems experience a large amount of sedimentation from agriculture, instream mining, and urban development. Sand and gravel mining affects golden orb habitat by causing headcutting upstream, increasing sedimentation concentrations in the water downstream, and causing channel instability downstream. Chemical contaminants have been documented throughout the range of the species and may represent a significant threat to the golden orb. However, the large populations in

the middle and lower Guadalupe River, lower San Antonio River, and San Marcos River indicate that some golden orb populations are not currently as vulnerable to habitat loss as others. Based upon our review of the best commercial and scientific data available, we conclude that the present or threatened destruction, modification, or curtailment of its habitat or range is an immediate threat of moderate magnitude to golden orb populations rangewide.

B. Overutilization for commercial, recreational, scientific, or educational purposes:

The golden orb is not a commercially valuable species and has never been harvested in Texas as a commercial mussel species (Howells 2010a, p. 12). Some scientific collecting occurs but is not likely to be a significant threat to the species because it occurs only rarely. However, handling mussels can disturb gravid females and result in glochidial loss and subsequent reproductive failure (Waller et. al 1995, p. 205). Additionally, handling has also been shown to reduce shell growth across mussel species, including several species of *Lampsilis* (Haag and Commens-Carson 2008, pp. 505–506). Repeated handling by researchers may adversely affect golden orb individuals, but these activities are occurring rarely and are not likely to threaten populations. Handling for scientific purposes contributes to the long-term conservation of the species. We do not have any evidence of risks to the golden orb from overutilization for commercial, recreational, scientific, or educational purposes, and we have no reason to believe this factor will become a threat to the species in the future. Based upon the best scientific and commercial information available, we conclude that overutilization of the golden orb for commercial, recreational, scientific, or educational purposes does not pose a significant threat to the species rangewide.

C. Disease or predation:

Disease

Little is known about disease in freshwater mussels. However, disease is believed to be a contributing factor in documented mussel die-offs in other parts of the United States (Neves 1987, pp. 11–12). Diseases have not been documented or observed during any studies of golden orb.

Predation

Raccoons will prey on freshwater mussels stranded by low waters or deposited in shallow water or on bars following flooding or low water periods (Howells 2010c, p. 12). Predation of golden orb by raccoons may be occurring occasionally but there is no indication it is a significant threat to the status of the species.

Some species of fish feed on mussels, such as common carp, freshwater drum, and redear sunfish, all of which are common throughout the range of golden orb (Hubbs et al. 2008, pp. 19, 45, 53). Common species of flatworms are voracious predators of newly metamorphosed juvenile mussels of many species (Zimmerman et al. 2003, p. 30). Predation is a normal factor influencing population dynamics of a healthy mussel population; however, predation may amplify declines in small populations primarily caused by other factors.

Summary of Factor C

Disease in freshwater mussels is poorly known, and we do not have any information indicating it is a threat to the golden orb. Additionally, predation is a natural ecological interaction and we have no information indicating the extent of any predation is a threat to populations of golden orb. Based upon the best scientific and commercial information available, we conclude that disease or predation is not a threat to the golden orb.

D. The inadequacy of existing regulatory mechanisms:

The Act requires us to examine the adequacy of existing regulatory mechanisms with respect to threats that may place the golden orb in danger of extinction or increase its likelihood of becoming so in the future. Existing regulatory mechanisms that could affect threats to the golden orb include State and Federal laws such as the Texas Threatened and Endangered Species regulations, Texas freshwater mussel sanctuaries, State and Federal sand and gravel mining regulations, and regulation of point and non-point source pollution.

Texas Threatened and Endangered Species Regulations

On January 8, 2010, the Texas Parks and Wildlife Commission placed 15 species of freshwater mussels, including the golden orb, on the State threatened list (Texas Register 2010, pp. 6–10). Section 68.002 of the Texas Parks and Wildlife (TPW) Code and Section 65.171 of the Texas Administrative Code (TAC) prohibit the direct take of a threatened species, except under issuance of a scientific collecting permit. “Take” is defined in Section 1.101(5) of the TPW Code as collect, hook, hunt, net, shoot, or snare, by any means or device, and includes an attempt to take or to pursue in order to take. While this law protects individuals from take, it is difficult to enforce and does not provide any protection for golden orb habitat. Moreover, our assessment finds that the species is not threatened by take (see Factor B above). There are no State provisions under the Texas Threatened and Endangered Species Regulations for reducing or eliminating the threats (see Factor A above) that may adversely affect golden orb or its habitat. In addition, these State regulations do not call for development of a recovery plan that will restore and protect existing habitat for the species. For these reasons, we find that existing Texas regulatory mechanisms for State-listed threatened species are currently inadequate to protect golden orb and its habitat or to prevent further decline of the species.

Freshwater Mussel Sanctuaries

The TPWD has designated specific areas of streams and reservoirs as no harvest mussel sanctuaries (31 TAC, part 2, chapter 57, subpart B, Rule 57.157). The locations of the designated mussel sanctuaries were selected because they support populations of rare and endemic mussel species or are important for maintaining, repopulating, or allowing recovery of mussels in watersheds where they have been depleted. As a result of the designation of mussel sanctuaries, three of the golden orb populations are protected from harvesting disturbance of other species

(Howells 2010f, p. 12). Unfortunately, mussel sanctuaries only restrict the harvest of mussels and do not address other activities that may affect mussels or their habitats. Therefore, these designations provide no regulatory mechanisms to protect golden orb from habitat alteration.

State Sand and Gravel Mining Regulations

The TPWD has been responsible for regulating the “disturbance of taking” streambed materials since 1911 (Meador and Layher 1998, p. 11) and has issued several permits for ongoing activities within the golden orb range (for more information on the effects of sand and gravel mining on golden orb, please refer to “Sand and Gravel Mining” under Factor A in Five-Factor Evaluation). In addition to authorized activities, there are ongoing unauthorized sand and gravel mining activities within the range of golden orb. Sand and gravel mining may be one of the least regulated of all mining activities (Meador and Layher 1998, p. 10).

Clean Water Act

The U.S. Army Corps of Engineers (USACE) retains oversight authority and requires a permit for gravel and sand mining activities that deposit fill into streams under section 404 of the Clean Water Act (33 U.S.C. 1251 et seq.). Additionally, a permit is required under section 10 of the Rivers and Harbors Act (33 U.S.C. 401 et seq.) for navigable waterways. However, many mining operations do not fall under these two categories. For example, nationwide permits are issued by the USACE for types of projects that are presumed to have minimal environmental impacts. However, projects permitted by nationwide permits, such as small mining operations, may have cumulative effects on aquatic species like the golden orb through increased sedimentation and channel instability.

Point source discharges of potential contaminants within the range of the golden orb have been reduced since the inception of the Clean Water Act, but this reduction may not provide adequate protection for filter-feeding organisms that can be affected by extremely low levels of contaminants (see “Chemical Contaminants” under Factor A). The EPA’s established water quality criteria may not be protective of mussels. Current water quality standards applied by EPA were established to be protective of aquatic life; however, freshwater mussels were not used to develop these standards (EPA 2005, p. 5), and current research reveals mussels to be more sensitive to many aquatic pollutants than the tested organisms (Augsperger et al. 2007, p. 2025). For example, Augspurger et al. (2003, p. 2572) and Sharpe (2005, p. 28) suggested that the criteria for ammonia may not be sufficient to prevent impacts to mussels under current and future climate conditions. In addition, chronic copper concentrations lethal to juvenile freshwater mussels have been shown to be less than the EPA’s 1996 chronic water quality criterion for copper (Wang et al. 2007b, pp. 2052–2055). Based on this information, the existing EPA water quality criteria may not be sufficient to prevent negative effects to the golden orb.

Nonpoint source pollution such as sedimentation and chemical contamination is considered a significant threat to golden orb habitat; however, the Clean Water Act does not adequately protect golden orb habitat from nonpoint source pollution, because most activities that cause nonpoint source pollution are not regulated under the Clean Water Act.

Summary of Factor D

Despite some State and Federal laws protecting the species and water quality, the golden orb continues to decline due to the effects of habitat destruction, poor water quality, contaminants, and other factors. The regulatory measures described above are not sufficient to significantly reduce or remove the threats to the golden orb. Based upon our review of the best commercial and scientific data available, we conclude that the lack of existing regulatory mechanisms is an immediate threat of moderate magnitude to the golden orb.

E. Other natural or manmade factors affecting its continued existence:

Natural and manmade factors that threaten the golden orb include climate change, population fragmentation and isolation, and nonnative species.

Climate Change

It is widely accepted that changes in climate are occurring worldwide (International Panel on Climate Change (IPCC) 2007, p. 30). Understanding the effects of climate change on the golden orb is important because the disjunct nature of the remaining golden orb populations, coupled with the limited ability of mussels to migrate, makes it unlikely that the golden orb can adjust its range in response to changes in climate (Strayer 2008, p. 30). For example, changes in temperature and precipitation can increase the likelihood of flooding or increase drought duration and intensity, resulting in direct effects to freshwater mussels like the golden orb (Hastie et al. 2003, pp. 40–43; Golloday et al. 2004, p. 503). Because the range of the golden orb has been reduced to isolated locations, many with low population numbers in small rivers and streams, the golden orb is vulnerable to climatic changes that could decrease the availability of water or produce more frequent scouring flood events. Indirect effects of climate change may include declines in host fish populations, habitat reduction, and changes in human activity in response to climate change (Hastie et al. 2003, pp. 43–44).

For the next two decades, a warming of about 0.2 °C (0.4 °F) per decade is projected across the United States (IPCC 2007, p. 12), and hot extremes, heat waves, and heavy precipitation and flooding are expected to increase in frequency (IPCC 2007, p. 18). As with many areas of North America, central Texas is projected to experience an overall warming trend in the range of 2.5 to 3.3 °C (4.5 to 6 °F) over the next 50 to 200 years (Mace and Wade 2008, p. 656). Even under lower greenhouse gas emission scenarios, recent projections forecast a 2.8 °C (5 °F) increase in temperature and a 10 percent decline in precipitation in central Texas by 2080 to 2099 (Karl et al. 2009, pp. 123–124). Based on our current understanding of climate change, air temperatures are expected to rise and precipitation patterns are expected to change in areas occupied by the golden orb. Karl et al. (2009, p. 12) also suggests that climate change impacts on water resources in the southern Great Plains (including central Texas) are expected as rising temperatures and decreasing precipitation exacerbate an area already plagued by low rainfall, high temperatures, and unsustainable water use practices.

The disjunct nature of the remaining golden orb populations, coupled with the limited ability of mussels to migrate, makes it unlikely that golden orb can adjust their range in response to changes in climate (Strayer 2008, p. 30). Climate change could affect the golden orb through the combined effects of global and regional climate change, along with the increased probability of long-term drought. Climate change exacerbates threats such as habitat degradation from prolonged periods of drought, increased water temperature, and the increased allocation of water for municipal, agricultural, and industrial uses. Climate change may be a significant stressor that exacerbates existing threats by increasing the likelihood of prolonged drought. As such, climate change, in and of itself, may affect the golden orb, but the magnitude and imminence of the effects remain uncertain. Based upon our review of the best commercial and scientific data available, we conclude that the effects of climate change in the future will likely exacerbate the current and ongoing threats of habitat loss and degradation caused by other factors, as discussed above.

Population Fragmentation and Isolation

As with many freshwater mussels, several of the remaining populations of the golden orb are small and geographically isolated and thus are susceptible to genetic drift (change of gene frequencies in a population over time), inbreeding depression, and random or chance changes to the environment, such as toxic chemical spills (Watters and Dunn 1995, pp. 257–258) or dewatering. Inbreeding depression can result in death, decreased fertility, smaller body size, loss of vigor, reduced fitness, and various chromosomal abnormalities (Smith 1974, pp. 350). Despite any evolutionary adaptations for rarity, habitat loss and degradation increase a species' vulnerability to extinction (Noss and Cooperrider 1994, pp. 58–62). Numerous authors (including Noss and Cooperrider 1994, pp. 58–62; Thomas 1994, p. 373) have indicated that the probability of extinction increases with decreasing habitat availability. Although changes in the environment may cause populations to fluctuate naturally, small and low-density populations are more likely to fluctuate below a minimum viable population (the minimum or threshold number of individuals needed in a population to persist in a viable state for a given interval) (Gilpin and Soule 1986, pp. 25–33; Shaffer 1981, p. 131; Shaffer and Samson 1985, pp. 148–150).

Historically, the golden orb was widespread throughout much of the Guadalupe River system and in portions of the Nueces-Frio River system when few natural barriers existed to prevent migration (via host species) among suitable habitats. The extensive impoundment of the Nueces, Guadalupe, and San Antonio River basins by the construction of dams has fragmented the few remaining golden orb populations throughout these river systems. For fertilization, golden orb females need an upstream male to release sperm; populations with few individuals reduce the likelihood that females will be exposed to sperm while siphoning. Therefore, recruitment failure is a potential problem for many small populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations. If downward population trends continue, further significant declines in total golden orb population size and consequent reduction in long-term survivability may soon become apparent.

Small golden orb populations, including those in Lake Corpus Christi Reservoir, the upper Guadalupe River in Kerr County, and the San Antonio River in Victoria County, may now be below the minimum population size required to maintain population viability into the future, since they are less likely to be able to recover through recruitment from events that reduce but do not extirpate populations. Additionally, these small populations are more vulnerable to extirpation from stochastic events, as the lack of connectivity among populations does not permit nearby populations to recolonize areas affected by intense droughts, toxic spills, or other isolated events that result in significant mussel die-offs. While the small, isolated populations do not represent an independent threat to the species, the situation does substantially increase the risk of extirpation from the effects of all other threats, including those addressed in this analysis, and those that could occur in the future from unknown sources.

Based upon our review of the best commercial and scientific data available, we conclude that fragmentation and isolation of small remaining populations of the golden orb are occurring and are ongoing threats to the species throughout all of its range.

Nonnative Species

Various nonnative species of aquatic organisms are firmly established within the range of the golden orb and pose a threat to the species. Golden algae (*Prymnesium parvum*) is a microscopic algae considered to be one of the most harmful algal species to fish and other gill-breathing organisms (Lutz-Carrillo et al. 2010, p. 24). Golden algae was first discovered in Texas in 1985 and is presumed to have been introduced from western Europe (Lutz-Carrillo et al. 2010, p. 30). Since its introduction, golden algae has been found in Texas rivers and lakes, including two lakes in central Texas (Baylor University 2009, p. 1). Under certain environmental conditions, golden algae can produce toxins that can cause massive fish and mussel kills (Barkoh and Fries 2010, p. 1; Lutz-Carrillo et al. 2010, p. 24). Evidence shows that golden algae probably caused fish kills in Texas as early as the 1960s, but the first documented fish kill due to golden algae in inland waters of Texas occurred in 1985 on the Pecos River in the Rio Grande basin (TPWD 2002, p. 1). The range of golden algae has increased to include portions of the Brazos and Colorado River basins, among others, and it has been responsible for killing more than 8 million fish in the Brazos River since 1981 and more than 2 million fish in the Colorado River since 1989 (TPWD 2010a, p. 1). Although actual mussel kills in Texas due to golden algae have not been recorded in the past, the toxin can kill mussels. Therefore, the elimination of host fish and the poisonous nature of the toxin to mussels make future golden algae blooms a threat to the golden orb.

An additional nonnative species, the zebra mussel (*Dreissena polymorpha*) are a potential threat to the golden orb. This invasive species has been responsible for the extirpation of freshwater mussels in other regions of the United States, including the Higgin's eye (*Lampsilis higginsii*) in Wisconsin and Iowa (Service 2006, pp. 9–10). Zebra mussels attach in large numbers to the shells of live native mussels and are implicated in the loss of entire native mussel beds (Ricciardi et al. 1998, p. 615). This fouling impedes locomotion (both laterally and vertically), interferes with normal valve movements, deforms valve margins, and essentially suffocates and starves the native mussels by depleting the surrounding water of oxygen and food (Strayer 1999, pp. 77–80). Heavy infestations of zebra mussels on native mussels may overly stress the animals by reducing their

energy reserves. Zebra mussels may also filter the sperm and possibly glochidia of native mussels from the water column, thus reducing reproductive potential. Habitat for native mussels may also be degraded by large deposits of zebra mussel pseudofeces (undigested waste material passed out of the incurrent siphon) (Vaughan 1997, p. 11).

Zebra mussels are not currently found within the range of the golden orb. However, a live adult zebra mussel was first documented in Lake Texoma on the Red River (on the north Texas border with Oklahoma) in 2009 (TPWD 2009a, p. 1). Since that time, additional zebra mussels have been reported from Lake Texoma, where they are now believed to be well established (TPWD 2009c, p. 1). New studies looking for the presence of zebra mussel DNA and zebra mussel larvae (veligers) within 14 north Texas reservoirs revealed that zebra mussel DNA was present in six of those reservoirs; however, none of those reservoirs contained veliger larvae, which suggests that zebra mussels have not become established in those lakes (TPWD 2011, p. 1). To date, Lake Texoma is the only reservoir known to harbor zebra mussels from all life stages. Zebra mussels are likely to spread to many other Texas reservoirs through accidental human transport (Schneider et al. 1998, p. 789). Although zebra mussels tend to proliferate in reservoirs or large pools, released zebra mussel veligers float downstream and attach to any hard surface available, rendering downstream golden orb populations extremely vulnerable to attachment and fouling. Because zebra mussels are so easily introduced to new locations, the potential for zebra mussels to continue to expand in Texas and invade the range of the golden orb is high. If this occurs, the golden orb is vulnerable to zebra mussel attachment and subsequent deprivation of oxygen, food, and mobility.

A molluscivore (mollusk eater), the black carp (*Mylopharyngodon piceus*) is a potential threat to the golden orb. The species has been commonly used by aquaculturists to control snails or for research in fish production in several States, including Texas (72 FR 59019, October 18, 2007). Black carp can reach more than 1.3 m (4 ft) in length and 150 pounds (68 kilograms (kg)) (Nico and Williams 1996, p. 6). Foraging rates for a 4-year old fish average 3 to 4 pounds (1.4 to 1.8 kg) a day, indicating that a single individual could consume 10 tons (9,072 kg) of native mollusks over its lifetime (Mississippi Interstate Cooperative Resource Association (MICRA) 2005, p. 1). Black carp can escape from aquaculture facilities. For example, in 1994 30 black carp escaped from an aquaculture facility in Missouri during a flood. Other escapes into the wild by non-sterile carp are likely to occur. Because of the high risk to freshwater mussels and other native mollusks, the Service recently listed black carp as an injurious species under the Lacey Act (72 FR 59019, October 18, 2007), which prevents importations and interstate transfer of this harmful species, but does not prevent its release into the wild once it is in the State. If the black carp were to escape within the range of the golden orb, it would likely negatively affect native mussels, including the golden orb.

Based upon our review of the best commercial and scientific data available, we conclude that

golden algae is an ongoing threat to the golden orb, and other nonnative species, such as zebra mussels and black carp, are a potential future threat to the golden orb that is likely to increase as these exotic species expand their occupancy within the range of the golden orb.

Summary of Factor E

The effects of climate change, while difficult to quantify at this time, are likely to exacerbate the current and ongoing threat of habitat loss caused by other factors, and the small sizes and fragmented nature of the remaining populations render them more vulnerable to extirpation. In addition, nonnative species, such as golden algae, currently threaten the golden orb, and the potential introduction of zebra mussels and black carp are potential future threats. Based upon our review of the best commercial and scientific data available, we conclude that other natural or manmade factors are immediate threats of moderate magnitude to the golden orb.

Conservation Measures Planned or Implemented :

The golden orb is listed as threatened by the TPWD in Texas and is a high priority species in the Texas Wildlife Action Plan 2005-2010 (TPWD 2005, p. 756). The Service, TPWD, academia, and other resource agencies have proposed and ongoing studies in Texas' river systems for Texas freshwater mussels, including the golden orb, observing life history parameters (including determination of ecological fish hosts), survivability of juveniles, monitoring habitat, and analyzing population dynamics. In addition, TPWD has established a Mussel Watch group.

The Service is currently working on forming and implementing the use of a Strategic Conservation Plan for Texas Freshwater Mussels that will result in additional conservation measures such as, best management practices, survey protocols, relocation protocols, and monitoring guidelines. The Service will be collaborating with other Federal, State, and non-governmental agencies during the formation and implementation of the Strategic Conservation Plan.

Summary of Threats :

This status review identifies threats to the golden orb attributable to Factors A, D, and E. The primary threat to the species is from habitat destruction and modification (Factor A) from impoundments, which scour riverbeds, thereby removing mussel habitat, decrease water quality, modify stream flows, and restrict fish host migration and distribution of freshwater mussels. Additional threats under Factor A include sedimentation, dewatering, sand and gravel mining, and chemical contaminants. Also, most of these threats may be exacerbated by the current and projected effects of climate change, population fragmentation and isolation, and the anticipated threat of nonnative species (discussed under Factor E). Threats to the golden orb are not being adequately addressed through existing regulatory mechanisms (Factor D). Because of the limited distribution of this endemic species and its lack of mobility, these threats are likely to lead to the extinction of the golden orb in the foreseeable future.

For species that are being removed from candidate status:

_____ Is the removal based in whole or in part on one or more individual conservation efforts that you determined met the standards in the Policy for Evaluation of Conservation Efforts When Making Listing Decisions(PECE)?

Recommended Conservation Measures :

Continued survey and monitoring efforts are needed throughout former and occupied sites to better define the species' distribution and status in the Guadalupe-San Antonio and Nueces-Frio River systems.

Continued biological and ecological research efforts are needed to identify host fish, spawning and brooding seasons, glochidia, and habitat and physiochemical parameters for golden orb. The Service will continue to work with TPWD, USGS, and others needed research in order to facilitate the conservation and preservation of the smooth pimpleback.

Long-term conservation measures need to be developed to facilitate and accomplish cooperative efforts between resource management agencies and private landowners. The development of candidate conservation agreements (with assurances) with interested parties would initiate conservation for the golden orb.

The Service will continue working with resource management agencies and the Texas Department of Transportation (TxDOT) on developing best management practices for proposed adjacent and instream impacts specific to Texas water systems.

The Service will continue working with resource management agencies and academia on developing a drought contingency plan that will facilitate the management and monitoring of mussel populations that harbor species of concern (i.e. the golden orb) during times of drought.

The Service will continue working with resource management agencies, TxDOT, and academia on the development of standard mussel survey, relocation, and monitoring protocols, which would establish a commonality among the wide variety of methods currently being used in Texas and would establish a baseline of what kind of data needs to be collected while conducting surveys.

Priority Table

Magnitude	Immediacy	Taxonomy	Priority
High	Imminent	Monotypic genus	1
		Species	2
		Subspecies/Population	3
	Non-imminent	Monotypic genus	4
		Species	5
		Subspecies/Population	6
Moderate to Low	Imminent	Monotypic genus	7
		Species	8
		Subspecies/Population	9
	Non-Imminent	Monotype genus	10
		Species	11
		Subspecies/Population	12

Rationale for Change in Listing Priority Number:

No change to listing priority number.

Magnitude:

We consider the threats that the golden orb faces to be moderate in magnitude. Habitat loss and degradation from impoundments, sedimentation, sand and gravel mining, and chemical contaminants are widespread throughout the range of the golden orb, but four large populations remain, including one that was recently discovered, suggesting that the threats are not high in magnitude.

Imminence :

We consider the threats to the golden orb as described in Factors A, D, and E under the Five-Factor Evaluation for Golden Orb to be imminent because these threats are ongoing and will continue in the foreseeable future. Habitat loss and destruction has already occurred and will continue as the human population continues to grow in central Texas. Several golden orb populations may already be below the minimum viable population requirement, which would cause a reduction in the number of populations and an increase in the species' vulnerability to extinction. These threats are exacerbated by climate change, which will increase the frequency and magnitude of droughts. Therefore, we consider these threats to be imminent.

 Yes Have you promptly reviewed all of the information received regarding the species for the purpose of determination whether emergency listing is needed?

Emergency Listing Review

 No Is Emergency Listing Warranted?

Description of Monitoring:

The TPWD Mussel Watch group has been conducting surveys throughout Texas and found several fresh dead golden orb in the Guadalupe-San Antonio and Nueces-Frio River systems. The groups continued efforts along with historic data has sparked the interest of academia to further survey efforts in the Colorado and Brazos River systems where a couple of large, stable, reproducing populations were discovered and are now being closely monitored. These recent discoveries will likely lead to increased survey and monitoring efforts throughout Texas.

Indicate which State(s) (within the range of the species) provided information or comments on the species or latest species assessment:

none

Indicate which State(s) did not provide any information or comment:

Texas

State Coordination:

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Approval/Concurrence:

Lead Regions must obtain written concurrence from all other Regions within the range of the species before recommending changes, including elevations or removals from candidate status and listing priority changes; the Regional Director must approve all such recommendations. The Director must concur on all resubmitted 12-month petition findings, additions or removal of species from candidate status, and listing priority changes.

Approve:



06/12/2015

Date

Concur:



12/15/2015

Date

Did not concur:

Date

Director's Remarks: